Network Systems Science & Advanced Computing

Biocomplexity Institute & Initiative

University of Virginia

Estimation of COVID-19 Impact in Virginia

August 5th, 2020

(data current to August 4th)

Biocomplexity Institute Technical report: TR 2020-094

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About Us

- Biocomplexity Institute at the University of Virginia
  - Using big data and simulations to understand massively interactive systems and solve societal problems
- Over 20 years of crafting and analyzing infectious disease models
  - Pandemic response for Influenza, Ebola, Zika, and others

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Overview

- **Goal**: Understand impact of COVID-19 mitigations in Virginia
- **Approach:**
  - Calibrate explanatory mechanistic model to observed cases
  - Project infections through the end of summer
  - Consider a range of possible mitigation effects in "what-if" scenarios
- **Outcomes:**
  - Ill, Confirmed, Hospitalized, ICU, Ventilated, Death
  - Geographic spread over time, case counts, healthcare burdens

Key Takeaways

Projecting future cases precisely is impossible and unnecessary.
Even without perfect projections, we can confidently draw conclusions:

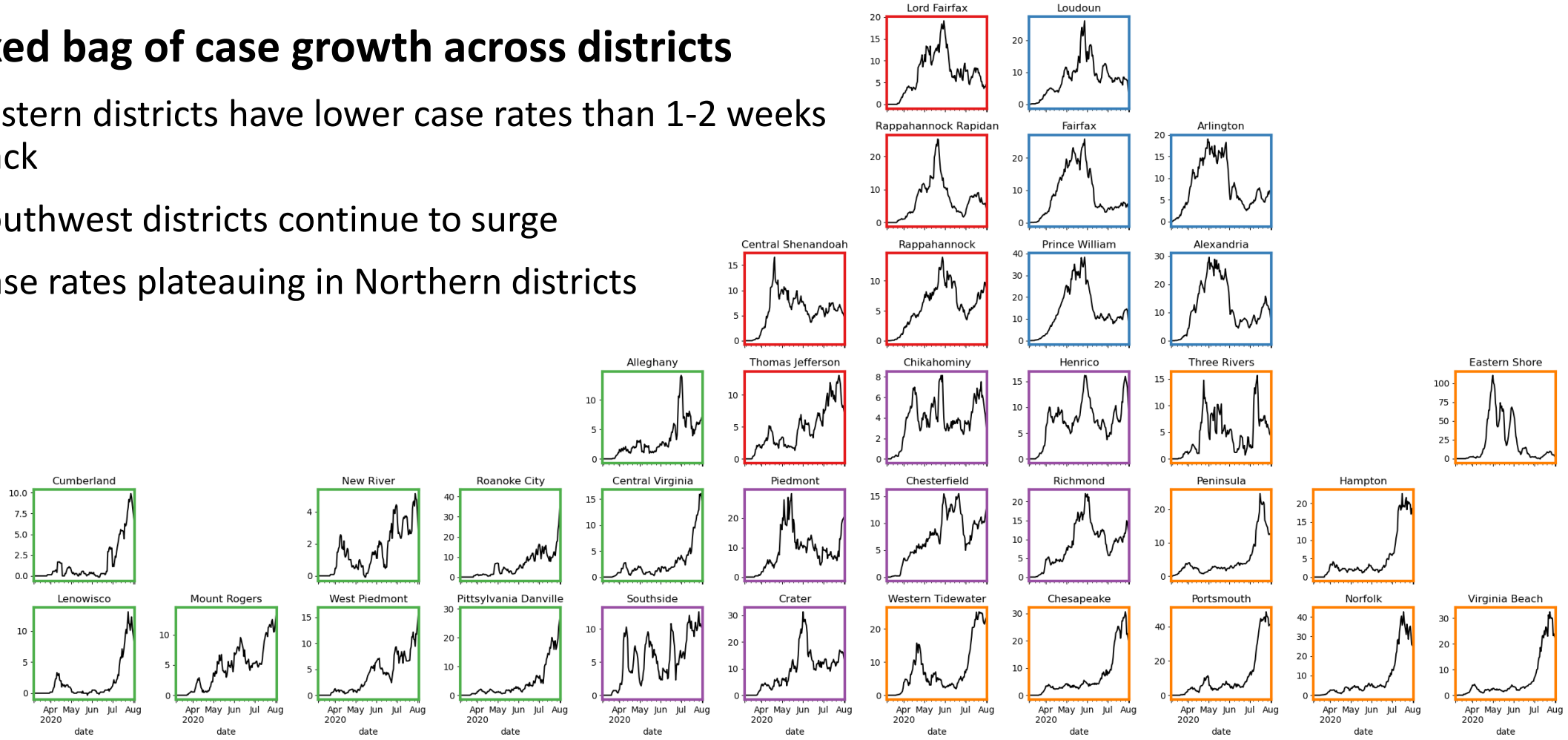
- **Case rates have decreased in Eastern districts. Some VDH districts still experiencing surge. Growth slowed state-wide.**
- Similar signs of slowed growth evident across nation, though incidence levels remain high.
- Given the experience of other states in the nation, it is crucial to maintain control**.**
- Recent model updates:
  - Include estimated Surge duration estimated from inflection search and peak detection
  - Continued evaluation of Adaptive Fitting procedure
- The situation is changing rapidly. Models will be updated regularly.

Situation Assessment

Case Rate (per 100k) by VDH District

Mixed bag of case growth across districts

- Eastern districts have lower case rates than 1-2 weeks back
- Southwest districts continue to surge
- Case rates plateauing in Northern districts



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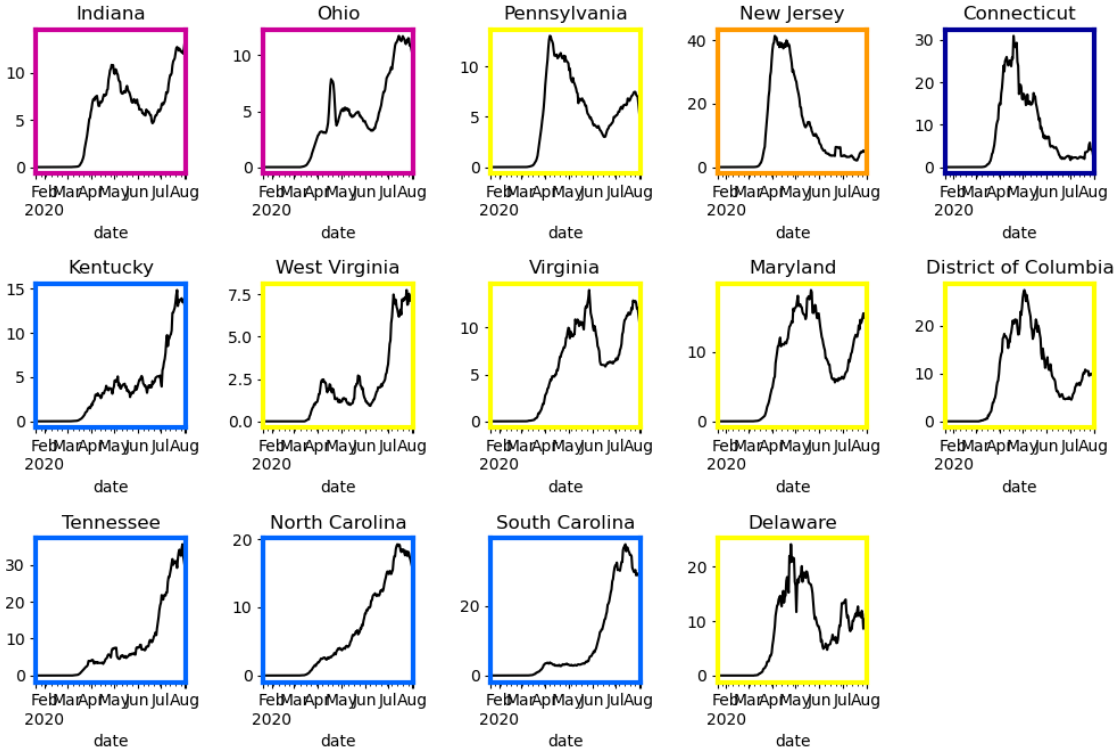
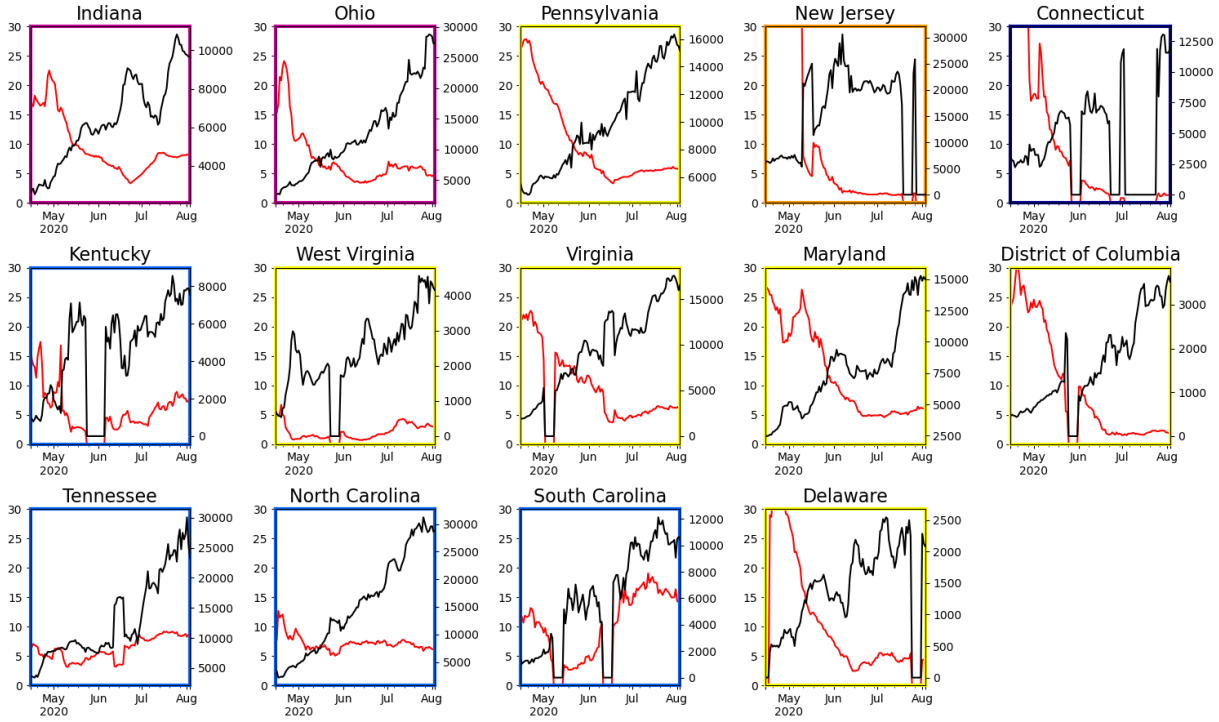
Other State Comparisons

Case Rate per 100K population



Multiple states experiencing local ‘peak’ in case rates in the past 2 weeks (possible exception MD, DC, TN)

Tests per Day and Test Positivity

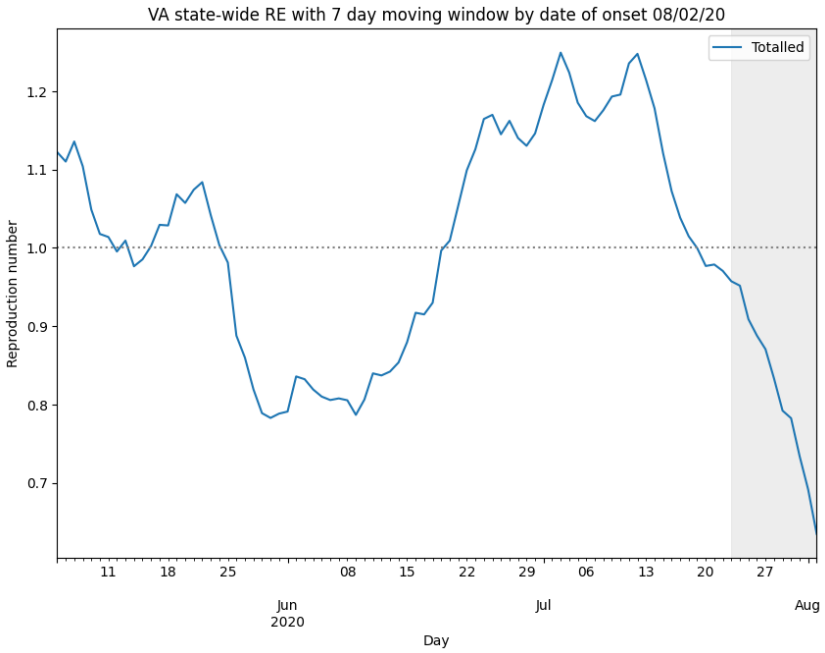


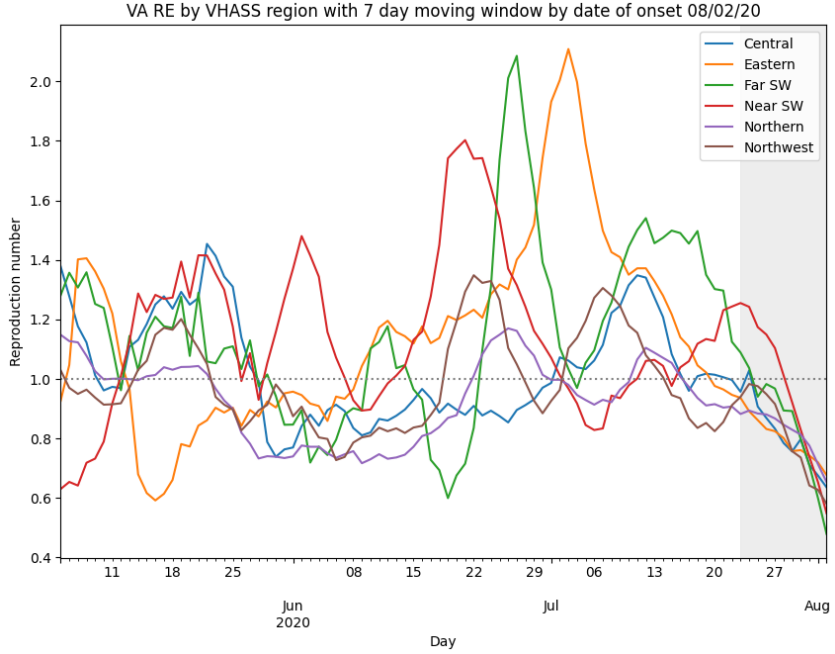
Test positivity rates hovering around 5-10% for most neighboring states despite increased testing levels

Estimating Daily Reproductive Number

July 25th Estimates

Region	Current R_e	Diff Last Week
State-wide	0.909	-0.051
Central	0.907	-0.030
Eastern	0.861	-0.138
Far SW	0.940	-0.514
Near SW	1.174	0.070
Northern	0.883	0.028
Northwest	0.975	0.180





Methodology

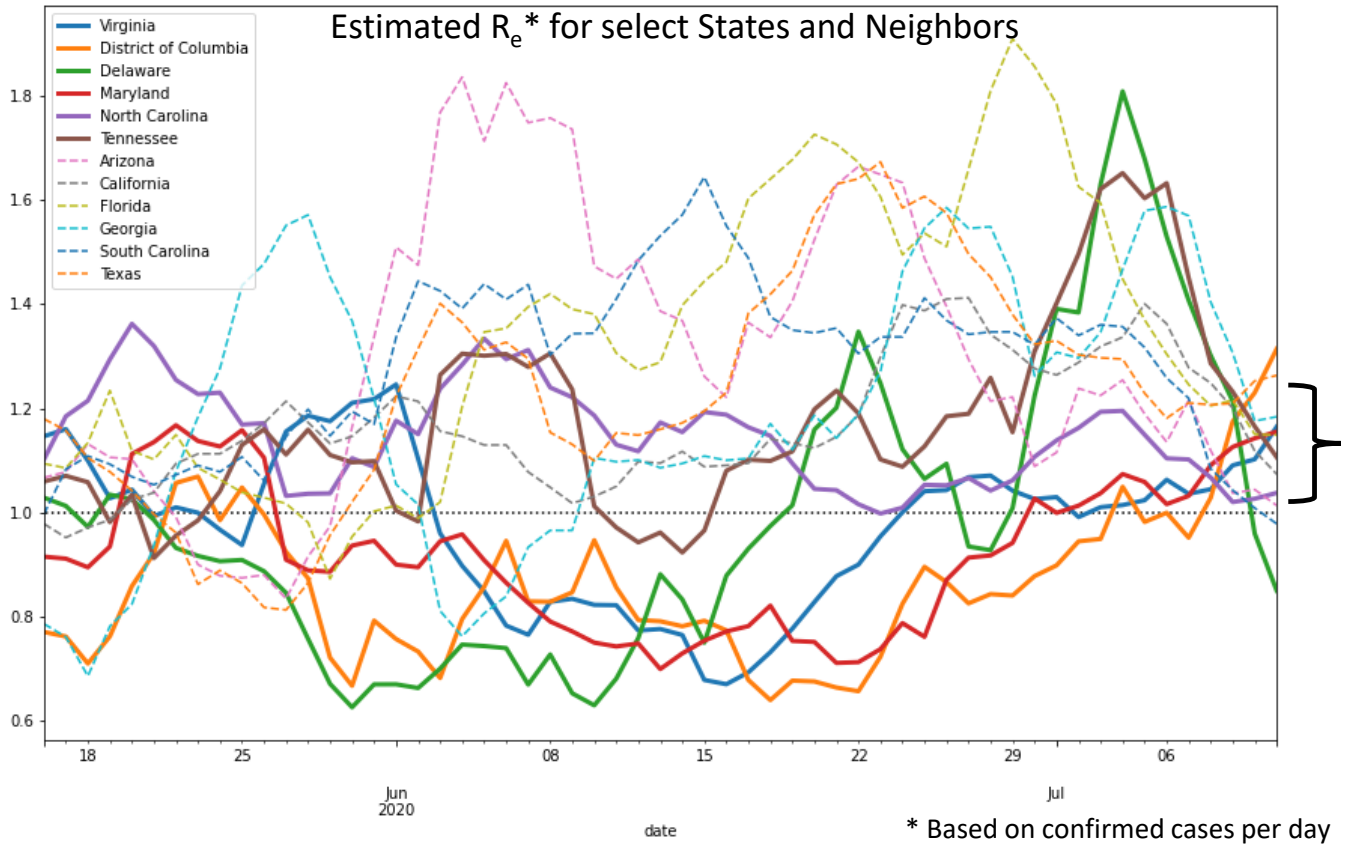
- Wallinga-Teunis method (EpiEstim[1]) for cases by date of onset
- Serial interval: 6 days (2 day std dev)
- Recent estimates may be unstable due to backfill

1. Anne Cori, Neil M. Ferguson, Christophe Fraser, Simon Cauchemez. A New Framework and Software to Estimate Time-Varying Reproduction Numbers During Epidemics. American Journal of Epidemiology, Volume 178, Issue 9, 1 November 2013, Pages 1505–1512, https://doi.org/10.1093/aje/kwt133

Other State Comparisons

Multiple states with R_e in the 1-1.2 range

- Recent national hotspots such as AZ, CA, TX, FL are decreasing
- Some neighboring states are trending upwards or remaining stable



* Based on confirmed cases per day

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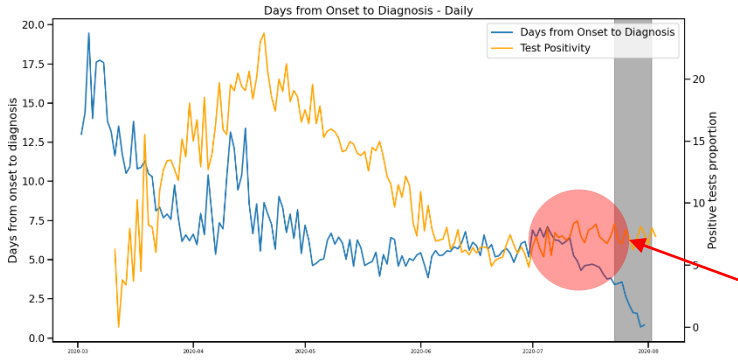
Changes in Case Detection

Days to Diagnosis dropped but rebounding

- Mid March to Late April = 8.0 days
- Late April to Mid May = 5.9 days (26% lower)
- Mid May to early June = 5.0 days (37% lower)
- Early June to mid July = 5.9 days (25% lower)

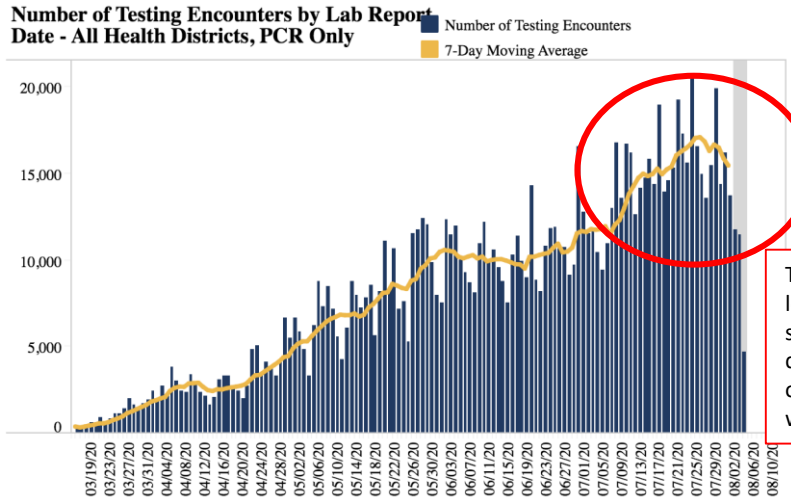
Returning to levels in early May

Test positivity vs. Onset to Diagnosis



Recent flattening / slight rise in test positivity

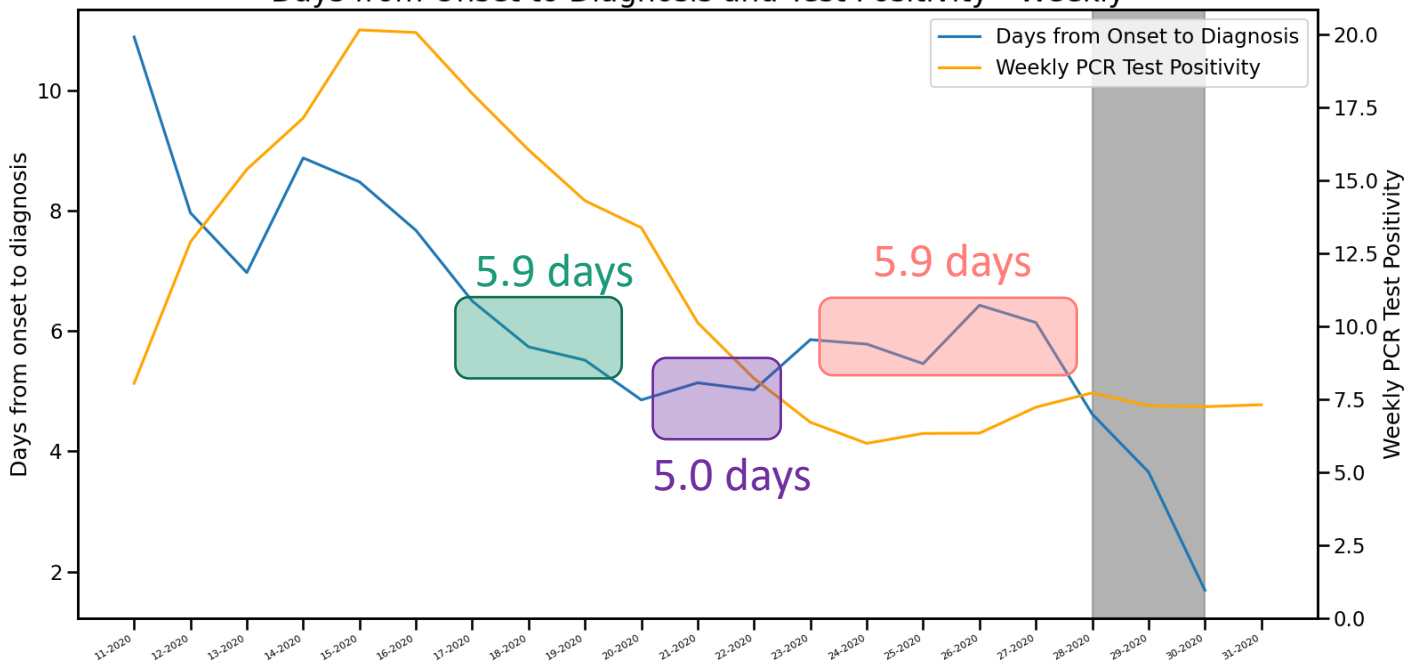
Testing Encounters and test positivity have steadied and increased



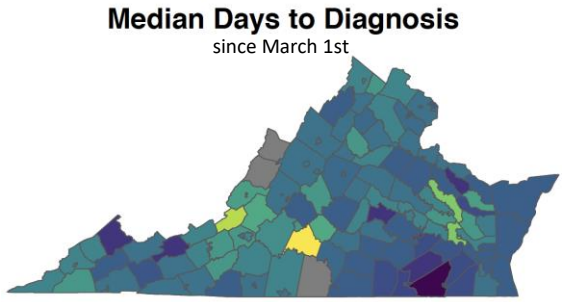
Testing levels slightly decreased over past 2 weeks

Accessed 10am August 5, 2020
https://www.vdh.virginia.gov/coronavirus/

Days from Onset to Diagnosis and Test Positivity - Weekly

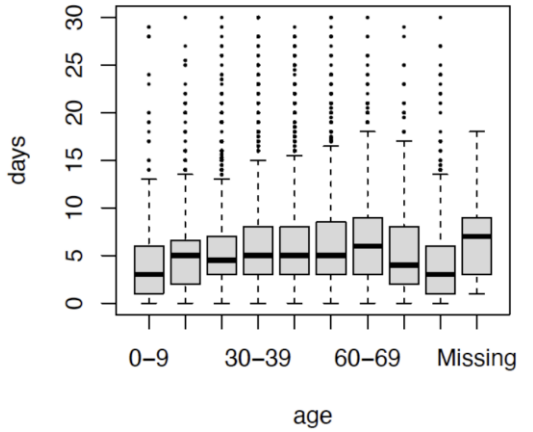


Changes in Case Detection – By District/Age

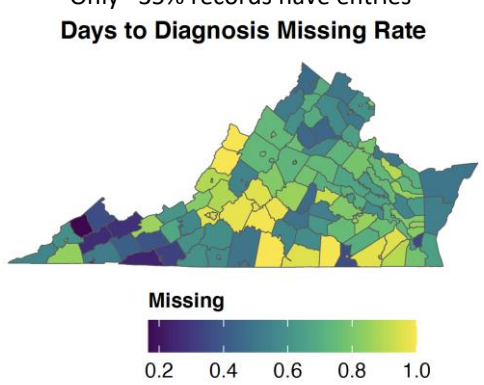


*up to the mid July when data is stable

Slight variations by age group
(0-9, 70-79 and 80-89 have lower medians)
No significant variation by severity (hosp./ICU)



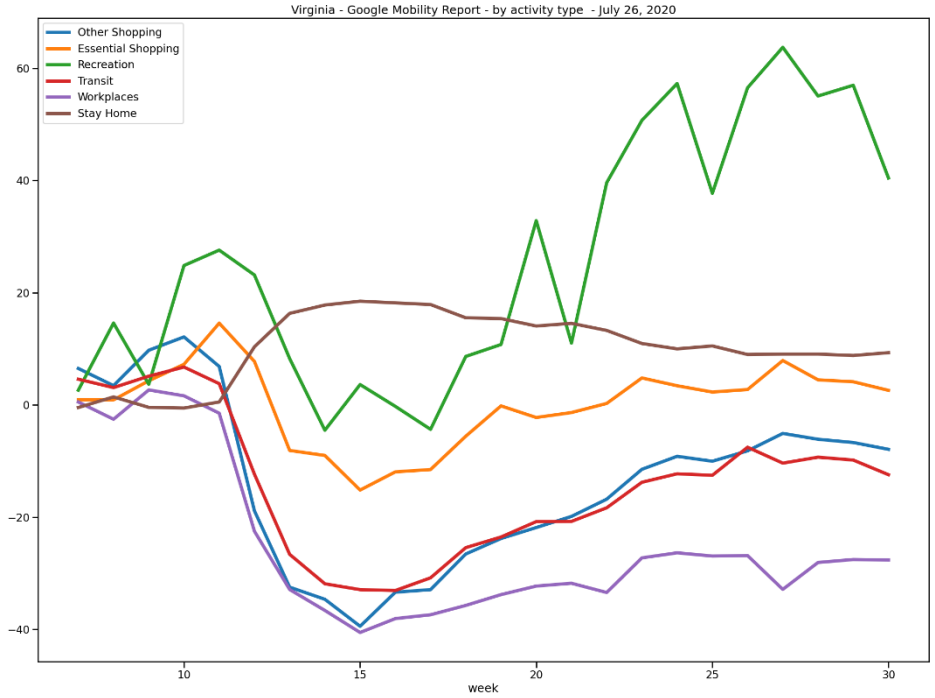
Only ~35% records have entries

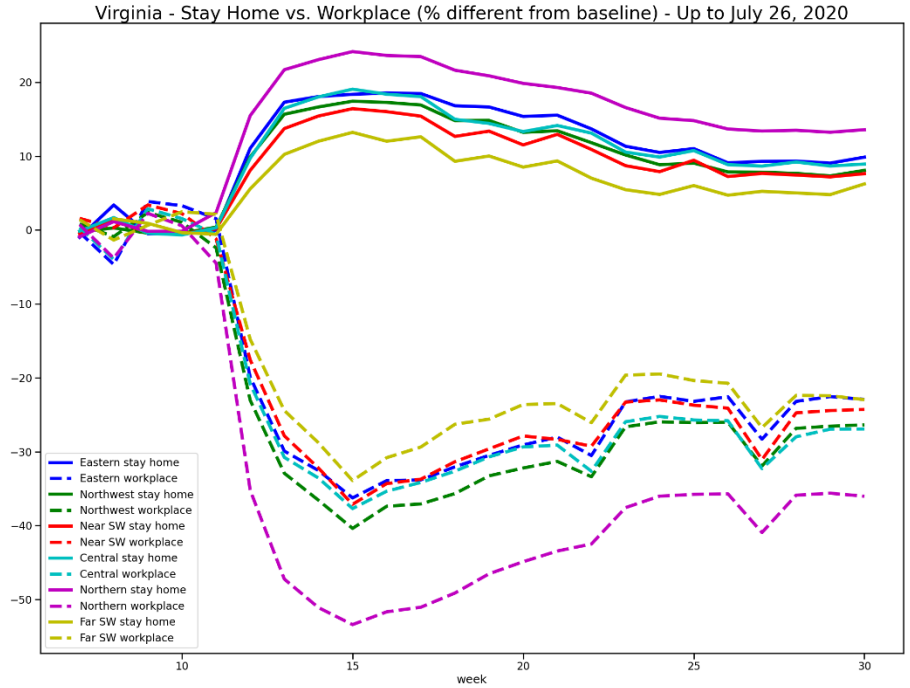


Estimating Effects of Social Distancing

Google Mobility data shows continued slow rebound (as of July 26th)
https://www.google.com/covid19/mobility/

- Continued slow reduction of those staying at home. Workplace levels remain low.
    - Urban/Rural variations in levels (e.g., Northern vs Far SW)
- Essential shopping back to baseline. Other shopping/transit trending towards baseline.
- Parks and recreation significantly higher than baseline (seasonal effects).

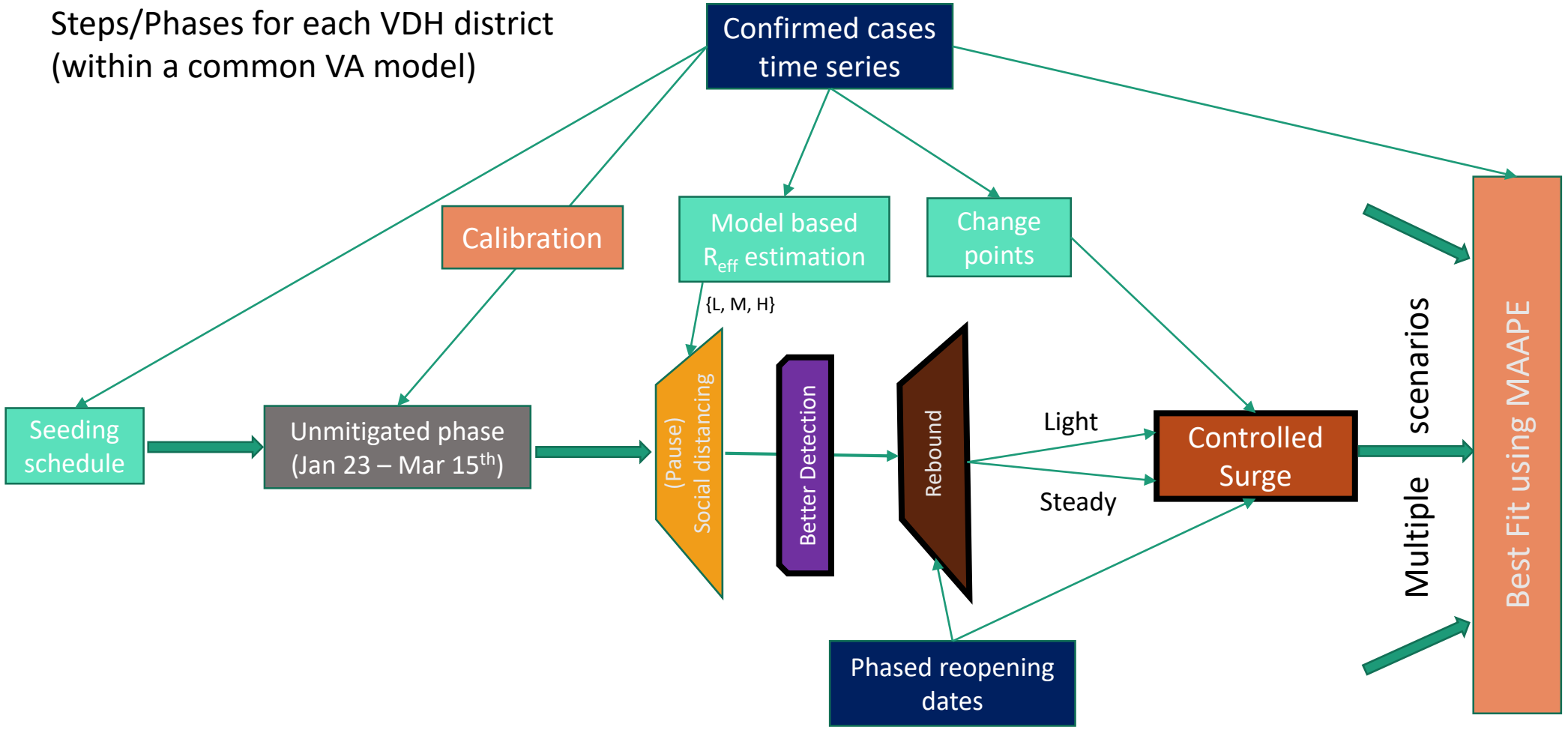




Scenario Updates

Forecasting by Projection Selection – VA COVID-19 Implementation

Steps/Phases for each VDH district
(within a common VA model)



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Eight Scenarios for Projection

Abbr	Rebound Intensity	Better Detection	Surge	Name
LR	Light	No	No	LightRebound
LR-S	Light	No	Yes	LightRebound-Surge
LR-BD	Light	Yes	No	LightRebound-BetterDetection
LR-BD-S	Light	Yes	Yes	LightRebound-BetterDetection-Surge
S	Steady	No	No	Steady
S-S	Steady	No	Yes	Steady-Surge
S-BD	Steady	Yes	No	Steady-BetterDetection
S-BD-S	Steady	Yes	Yes	Steady-BetterDetection-Surge

Allow “Best Fit” method to select from “Surge” scenarios

Historical Scenarios: Control

Pause from Social Distancing: Began on March 15th

- Lifted on May 15th (61 days), with two-week delay (75 days) for select counties*
- **Intensity**: Social distancing pauses and significantly reduces case growth, this level varies by VDH Health District and is fit through an analysis of growth rate during the Pause

Intensity of Rebound: Some districts rebounded following initial relaxation of Pause

- **Steady:** Intensity of effective mixing remains steady from Pause as infection control practices moderate increased interactions
- **Light:** Effective mixing returns to 1/6th of pre-pandemic levels
- **Full Rebound**: Interactions return completely (100%) to pre-pandemic levels, as a reference

Tracing and Isolation: Increased Testing Capacity coupled with infection control measures can limit the period of infectiousness without isolation

- **Better Detection**: Observed relative reductions in days from onset to diagnosis applied to infectious period from (30% → 45% → 30%) and remain stable into future for projections

* Select counties as mentioned by recent releases from Governor Northam's office
https://www.governor.virginia.gov/newsroom/all-releases/2020/may/headline-856741-en.html
https://www.governor.virginia.gov/newsroom/all-releases/2020/may/headline-856796-en.html

Ongoing Scenarios: Surge

Resurgence: Much of the nation experiencing a resurgence

- Many districts in the Commonwealth also showing a resurgence
- National: 28-day delay (avg) from relaxation to surge

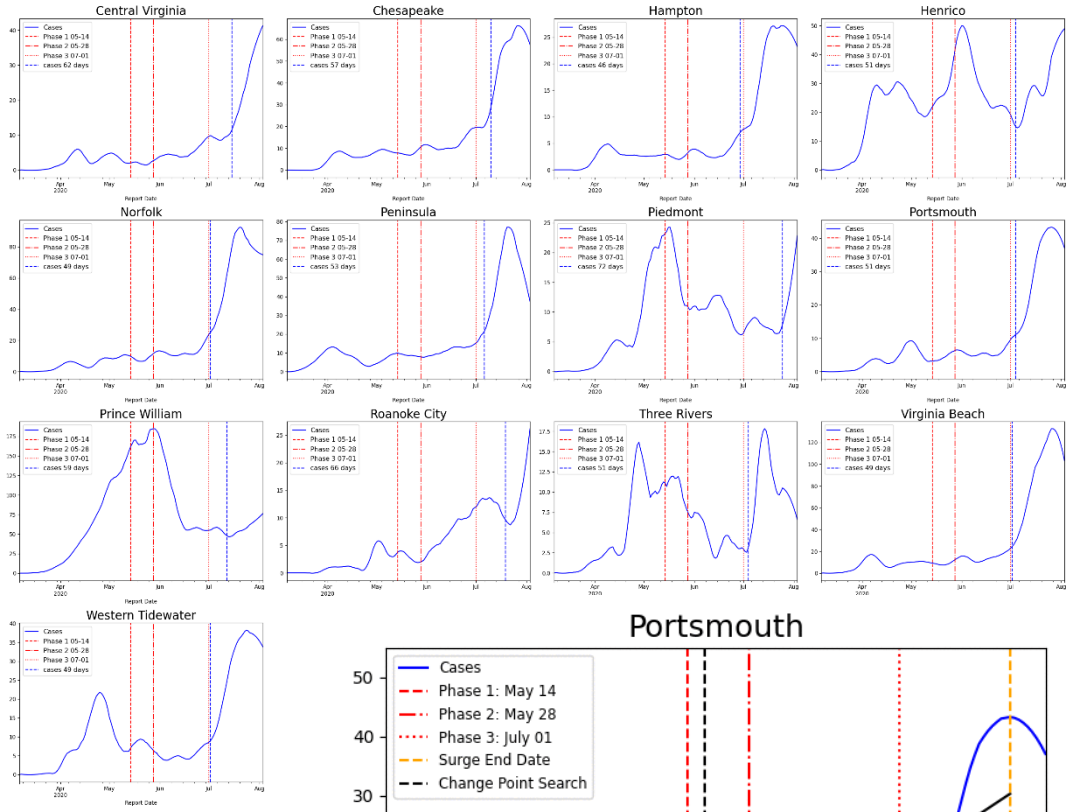
Intensity of Surge: Difficult to predict with limited data

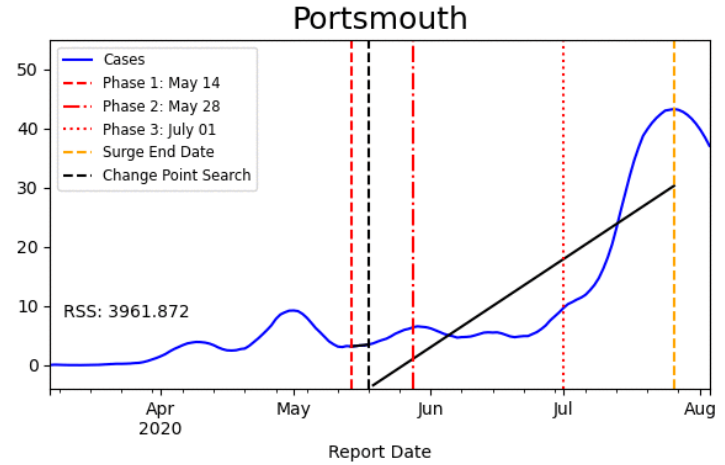
- **Strong Rebound:** Effective mixing returns 1/2 back to pre-pandemic levels

Timing of Surge: Past and Present

- Determine surging districts and timing - “hockey stick” fit
- Default to July 29th, (28 days from July 1st) for districts not identified
- Surge duration limited by observed or estimated peak
- Return to pre-surge levels (scenario-specific)

13 districts: Compared to 11 last week
In: Piedmont, Three Rivers, Prince William, Alleghany, Henrico
Out: Arlington, Pittsylvania-Danville, Rappahannock Rapidan

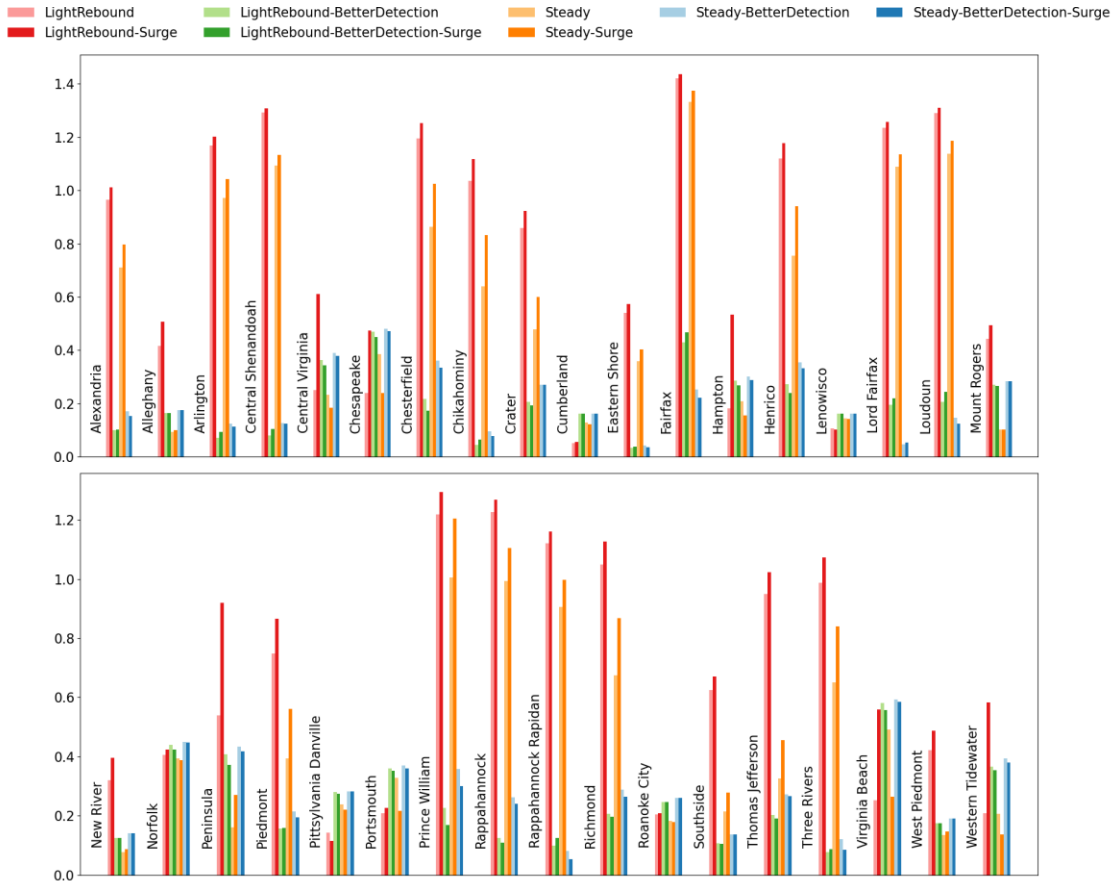




Model Results

Selection of Best Fitting Projection

Recent incidence by district (last week) is measured against all eight projections, one with least error is selected as the "Best Fit" projection

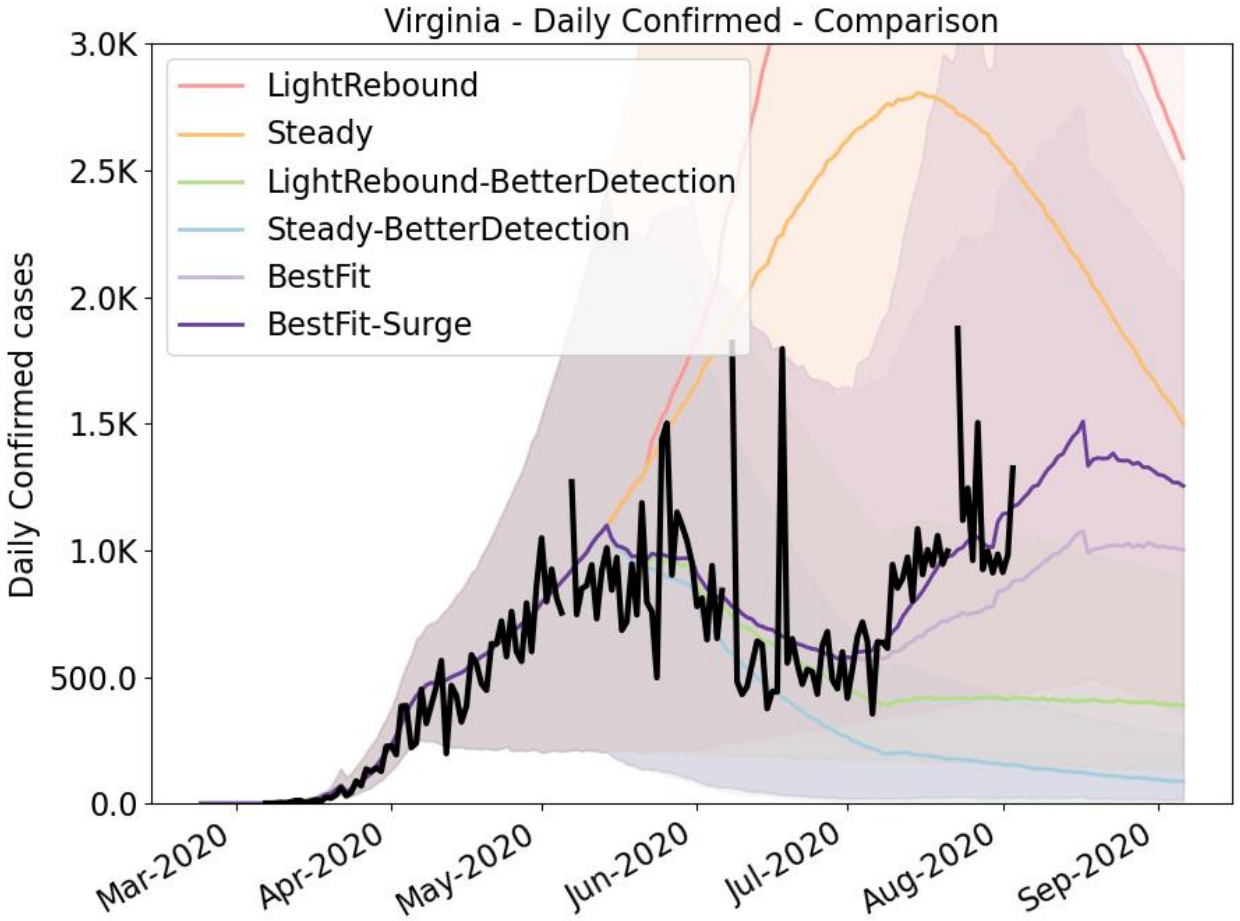


Abbr	Name	# of Districts (last wk)
LR	LightRebound	4 (3)
LR-S	LightRebound-Surge	2 (4)
LR-BD	LightRebound-BetterDetection	7 (15)
LR-BD-S	LightRebound-BetterDetection-Surge	8 (1)
S	Steady	5 (4)
S-S	Steady-Surge	5 (4)
S-BD	Steady-BetterDetection	1 (1)
S-BD-S	Steady-BetterDetection-Surge	3 (3)

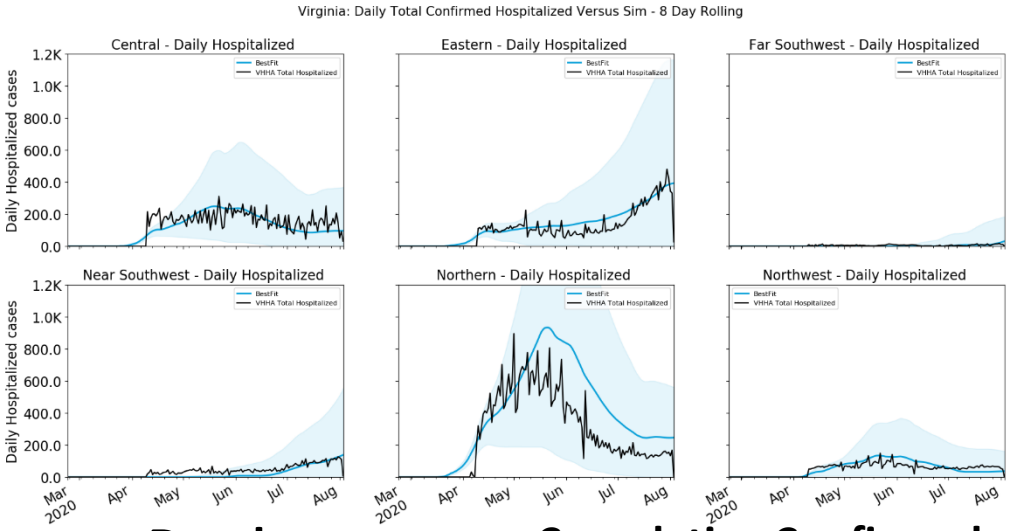
- 18 districts have Surge projections as BestFit compared to 12 last week
- Mixed movement some towards "higher incidence" projections and some towards "lower incidence"

Outcome Projections

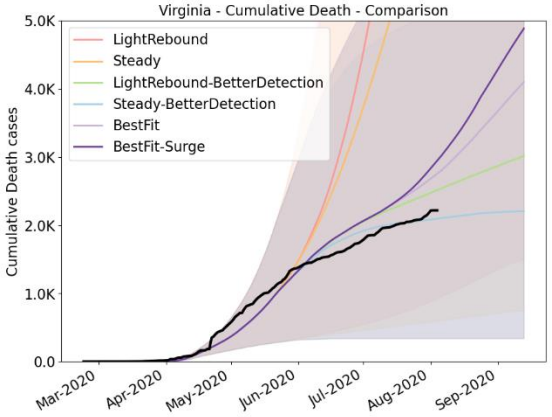
Confirmed cases



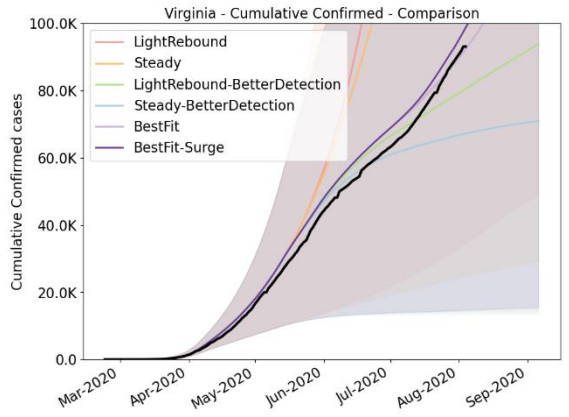
Hospital occupancy



Deaths



Cumulative Confirmed cases



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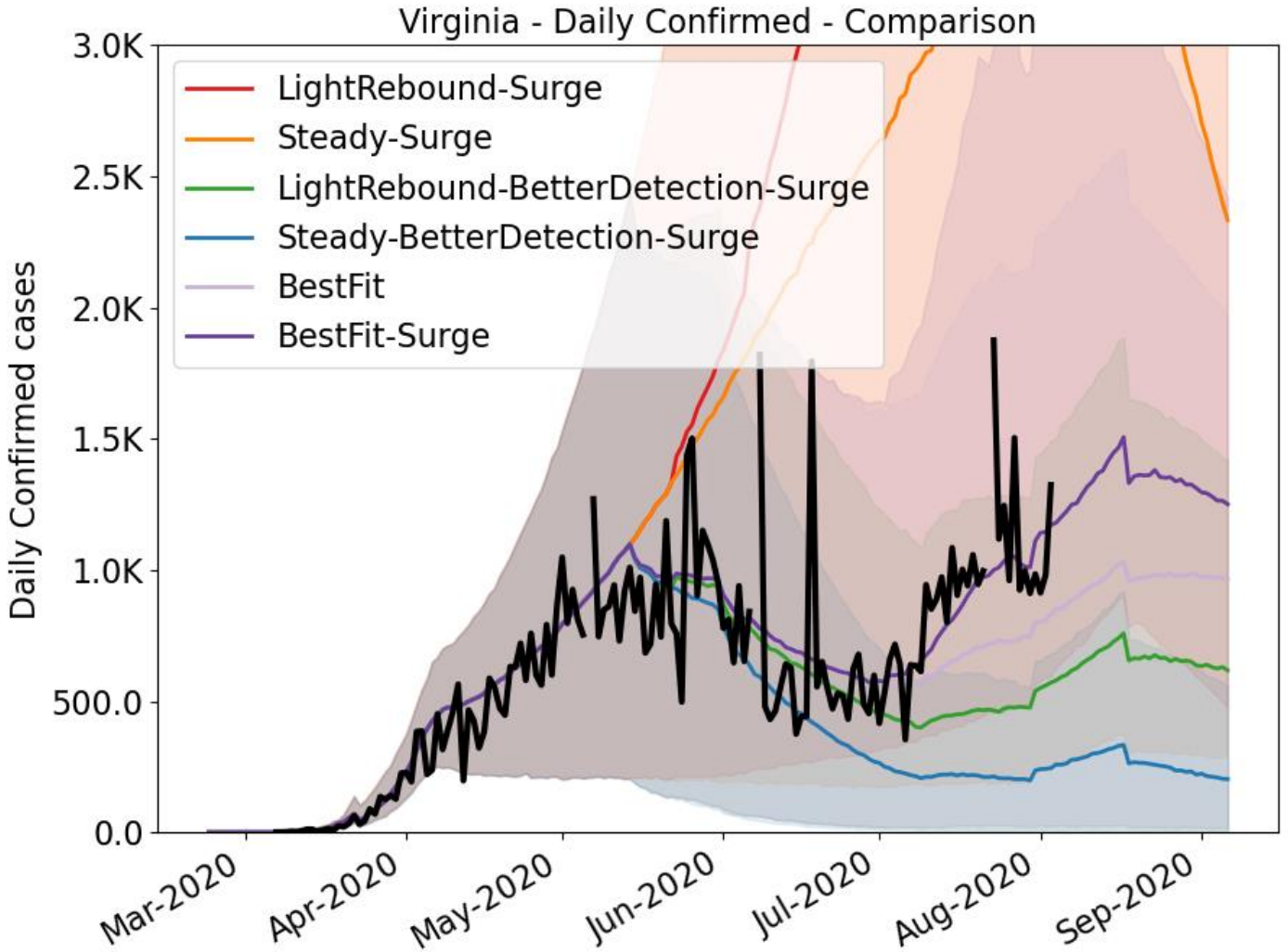
Outcome Projections – with Surge



Weekly New Confirmed Cases*

Week Ending	Best Fit	Best Fit w/ Surge
7/26/20	5,064	6,776
8/2/20	5,401	7,306
8/9/20	6,154	8,320
8/16/20	6,838	9,372
8/23/20	7,196	9,842
8/30/20	7,130	9,494
9/6/20	7,112	9,112

*Numbers are medians of projections

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District Level Projections – Daily

Best fitting projections by District

- Projections that best fit recent trends
- Daily confirmed cases by Region (blue solid) with simulation at the region level (black dotted)
- Projection color consistent with other and abbreviated in title

Abbr	Name	# of Districts (last wk)
LR	LightRebound	4 (3)
LR-S	LightRebound-Surge	2 (4)
LR-BD	LightRebound-BetterDetection	7 (15)
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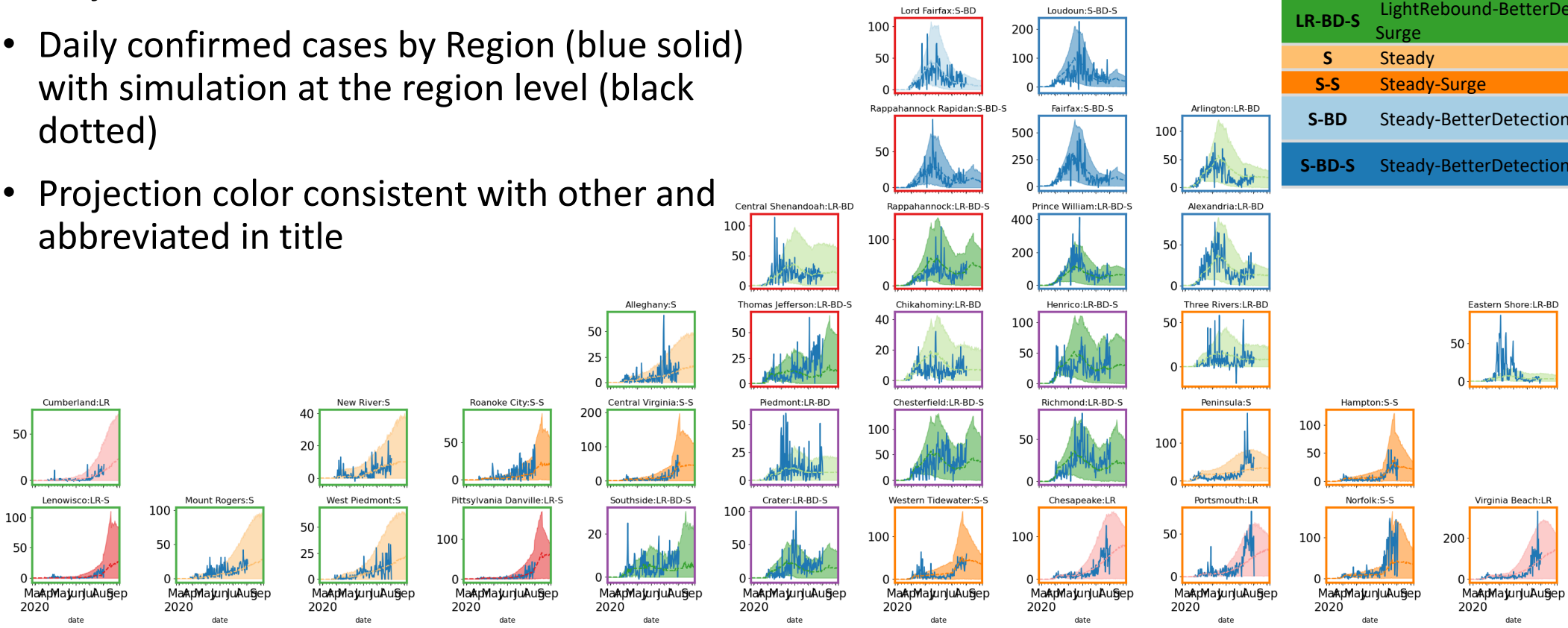

District Level Projections – Daily with Surge

Best fitting projections by District

- Projections that best fit recent trends with Surge assumed for all districts
- Daily confirmed cases by Region (blue solid) with simulation at the region level (black dotted)
- Projection color consistent with other and abbreviated in title

Abbr	Name	# of Districts (last wk)
LR	LightRebound	4 (3)
LR-S	LightRebound-Surge	2 (4)
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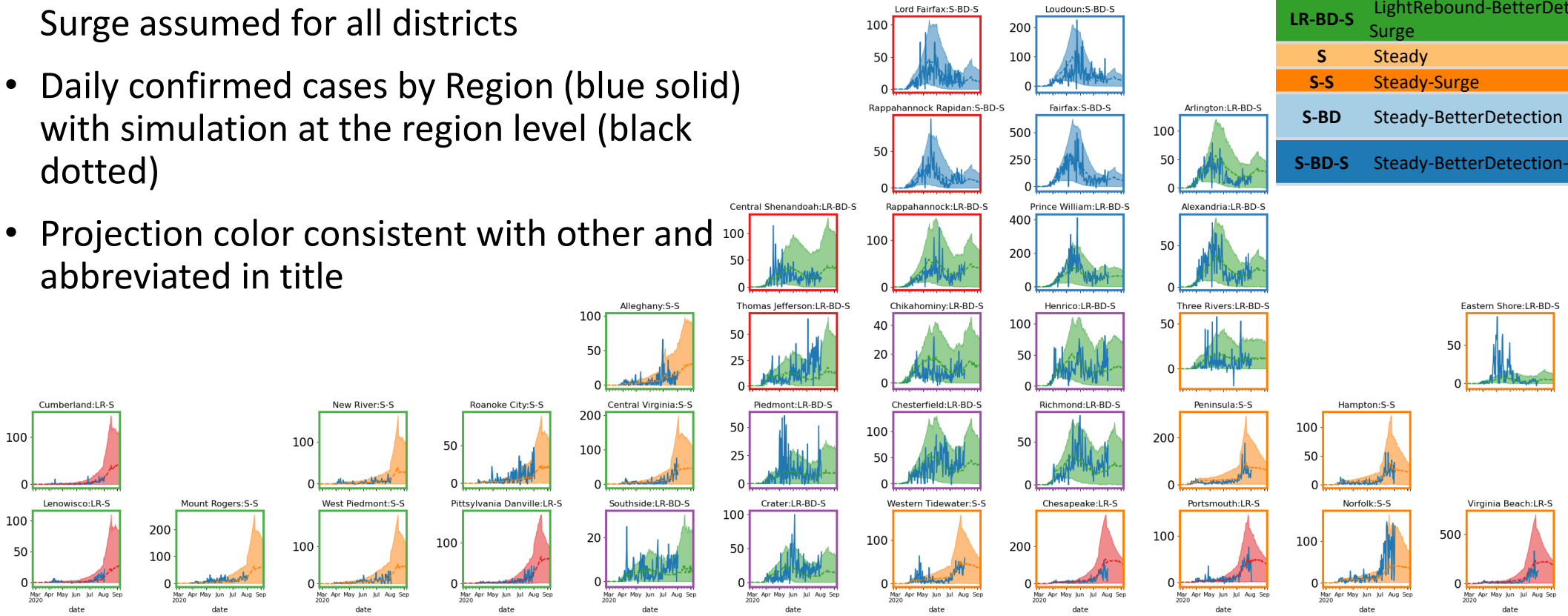

District Level Projections - Cumulative

Best fitting projections by District

- Projections that best fit recent trends
- Daily cumulative confirmed cases by Region (blue solid) with simulation at the region level (black dotted)
- Projection color consistent with other and abbreviated in title

Abbr	Name	# of Districts (last wk)
LR	LightRebound	4 (3)
LR-S	LightRebound-Surge	2 (4)
LR-BD	LightRebound-BetterDetection	7 (15)
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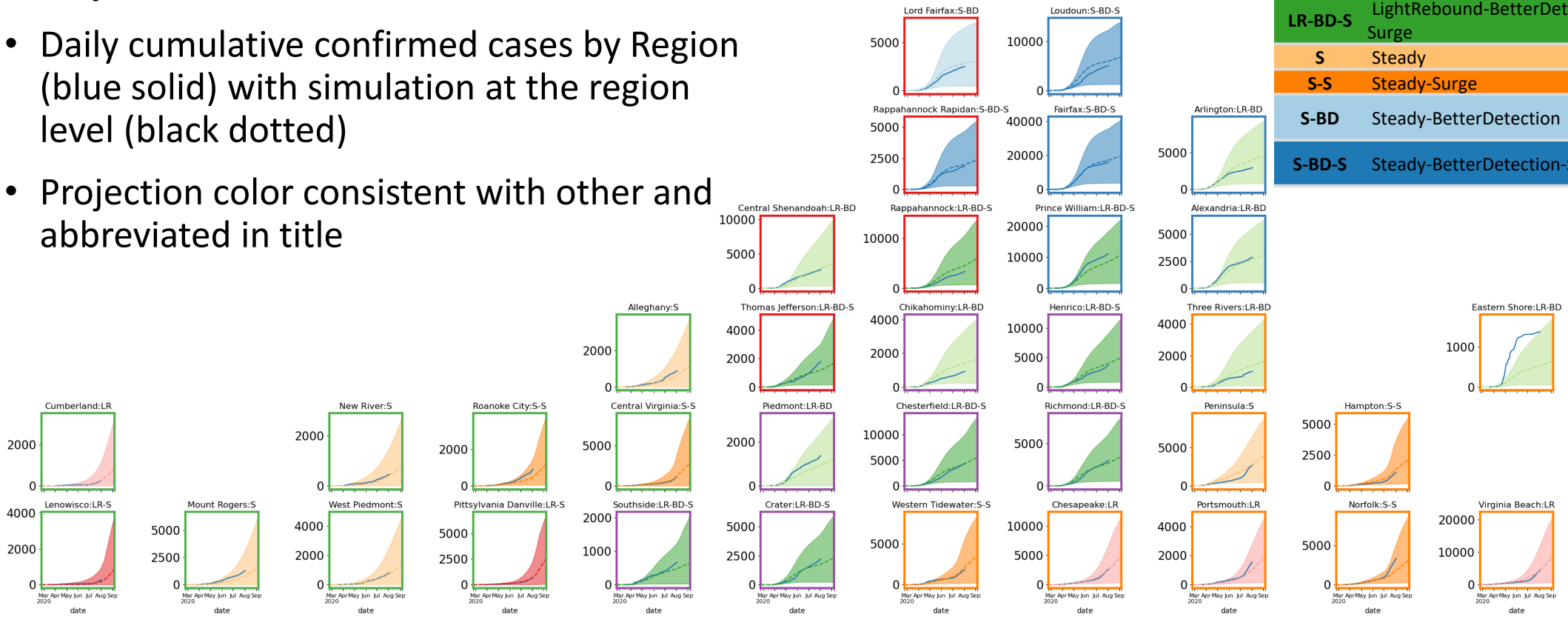
S	Steady	5 (4)
S-S	Steady-Surge	5 (4)
S-BD	Steady-BetterDetection	1 (1)
S-BD-S	Steady-BetterDetection-Surge	3 (3)



District Level Projections – Cumulative with Surge

Best fitting projections by District

- Projections that best fit recent trends with Surge assumed for all districts
- Daily confirmed cases by Region (blue solid) with simulation at the region level (black dotted)
- Projection color consistent with other and abbreviated in title

Abbr	Name	# of Districts (last wk)
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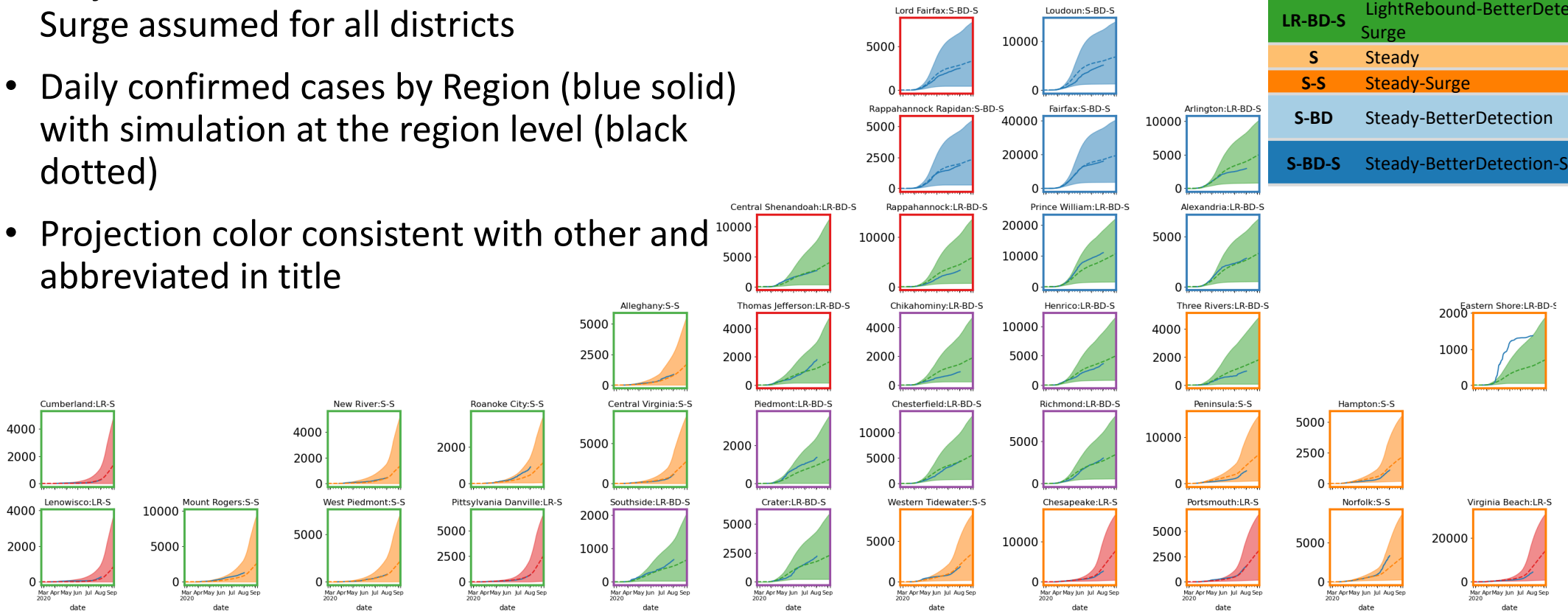
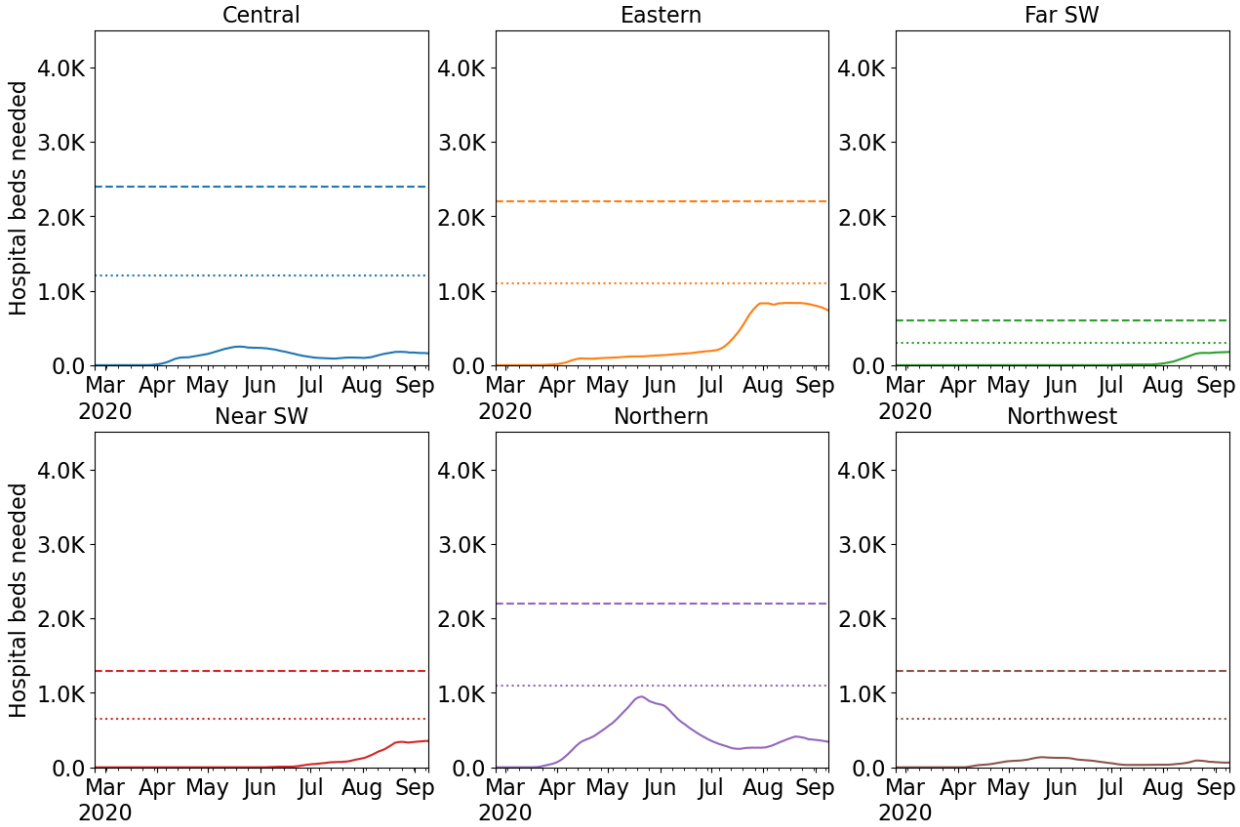


Hospital Demand and Capacity by Region

Capacities by Region – BestFit-Surge

COVID-19 capacity ranges from 80% (dots) to 120% (dash) of total beds



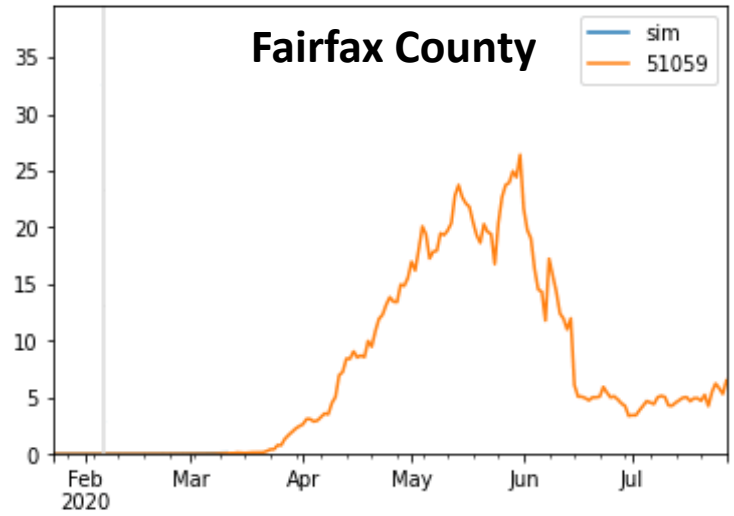
- Based on current best fits with controlled surge
  - Recent changes in case rates have reduced the likelihood of exceeding 80% capacity by end of August
  - However, multiple regions could potentially exceed capacity depending on fall scenarios
  - Will be re-evaluated when model horizons are updated
- Activity in neighboring states and reopening of schools/universities may make this more likely

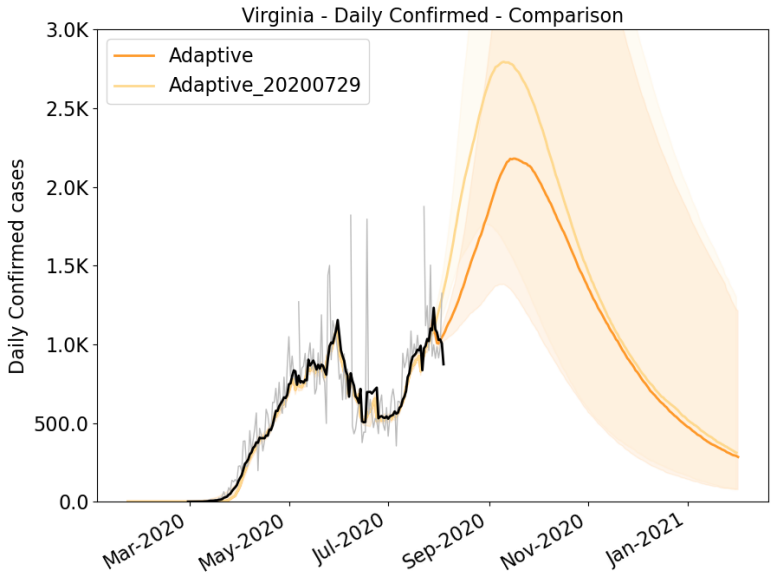
* Assumes average length of stay of 8 days

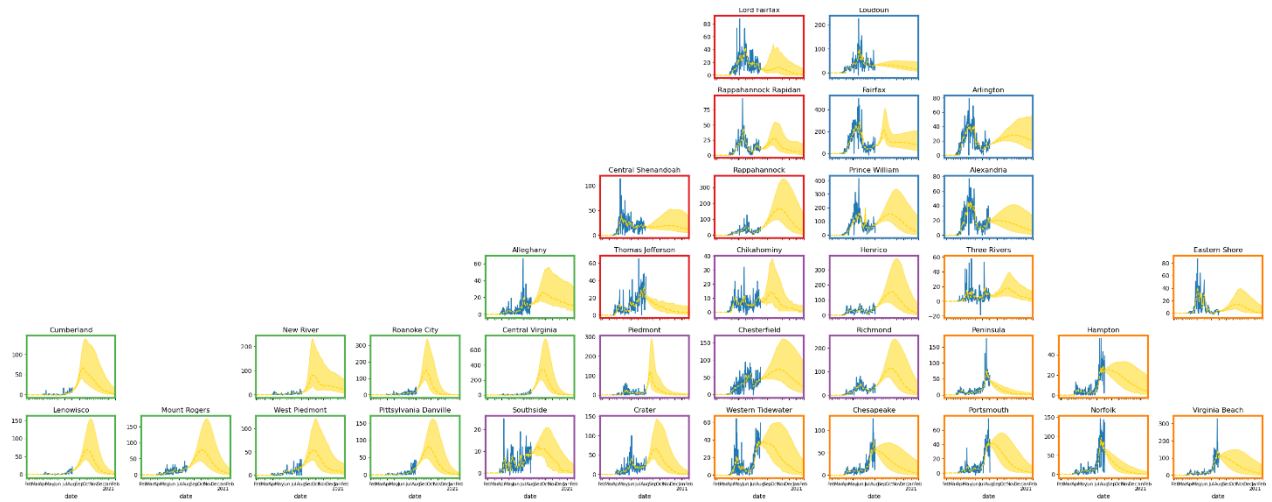
Preliminary Use of Adaptive Fitting for Calibration

Each county fit precisely, with recent trends used for future projection

- Rather than a few scenarios used to represent all courses, the daily transmission rate is fitted in a county-specific SEIR model
- Allows history to be precisely captured, but can still layer in future projection scenarios
- Uncertainty obtained by sweeping over impacts of testing rate and other disease parameters







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Key Takeaways

Projecting future cases precisely is impossible and unnecessary.
Even without perfect projections, we can confidently draw conclusions:

- **Case rates have decreased in Eastern districts. Some VDH districts still experiencing surge. Growth slowed state-wide.**
- Similar signs of slowed growth evident across nation, though incidence levels remain high.
- Given the experience of other states in the nation, it is crucial to maintain control**.**
- Recent model updates:
  - Include estimated Surge duration estimated from inflection search and peak detection
  - Continued evaluation of Adaptive Fitting procedure
- The situation is changing rapidly. Models will be updated regularly.

References

Venkatramanan, S., et al. "Optimizing spatial allocation of seasonal influenza vaccine under temporal constraints." *PLoS computational biology* 15.9 (2019): e1007111.

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Biocomplexity page for data and other resources related to COVID-19: https://covid19.biocomplexity.virginia.edu/

Questions?

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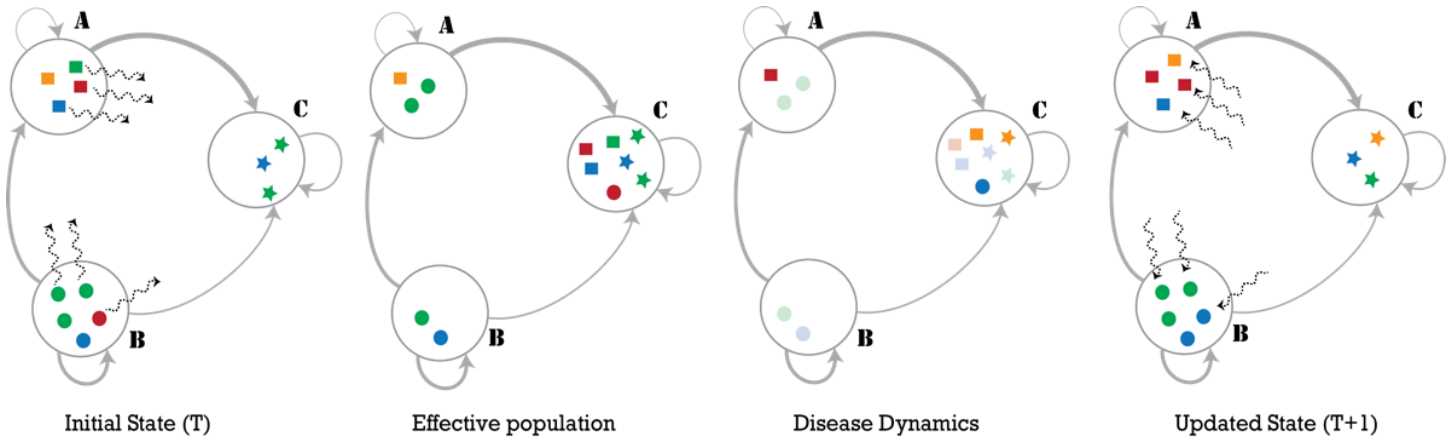
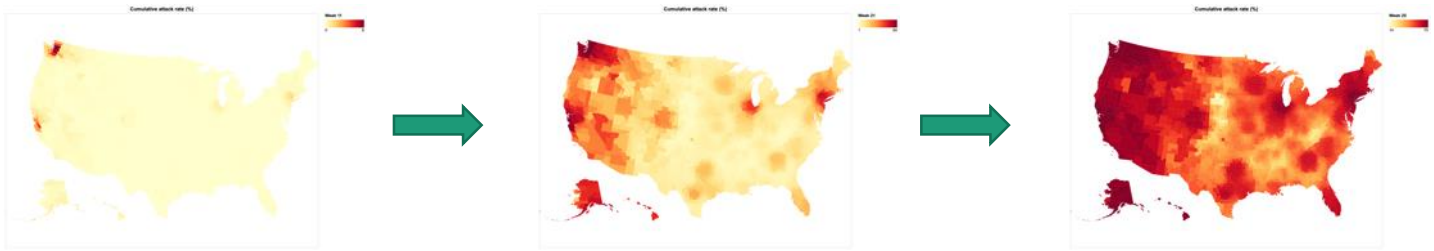
Basic Model Configuration

Simulation Engine – PatchSim

- Metapopulation model
  - Represents each population and its interactions as a single patch
  - 133 patches for Virginia counties and independent cities
- Extended SEIR disease representation
  - Includes asymptomatic infections and treatments
- Mitigations affect both disease dynamics and population interactions
- Runs fast on high-performance computers
  - Ideal for calibration and optimization





Venkatramanan, Srinivasan, et al. "Optimizing spatial allocation of seasonal influenza vaccine under temporal constraints." *PLoS Computational Biology* 15.9 (2019): e1007111.

Model Configuration

- **Transmission:** Parameters are calibrated to the observed case counts
  - **Reproductive number:** 2.1 - 2.3
  - **Infectious period** (time of infectiousness before full isolation): 3.3 to 5 days
- **Initial infections:** Start infections from confirmed cases by county
  - Timing and location based on onset of illness from VDH data
  - Assume 15% detection rate, so one confirmed case becomes ~7 initial infections
- **Mitigations:** Intensity of social distancing rebound and control sustaining mitigations into the future are unknowable, thus explored through 5 scenarios

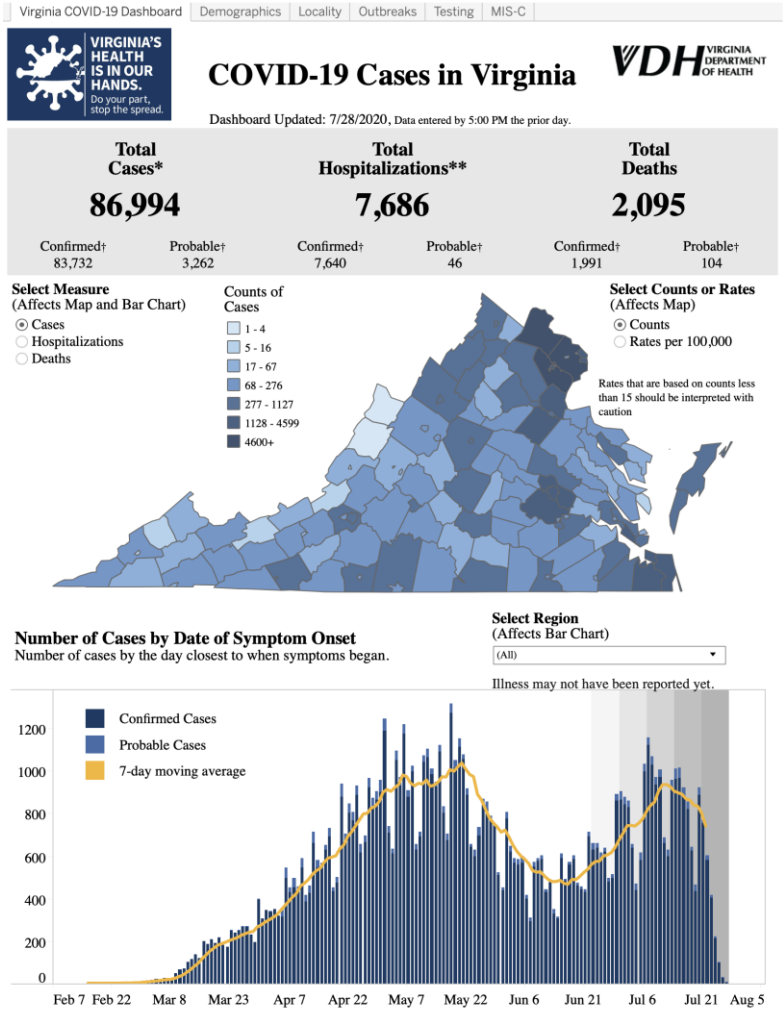
Full Model Parameters

	Parameter	Values	Description
Transmission	Transmissibility (R_0)[1]	2.2 [2.1 – 2.3]	Reproductive number
	Incubation period[1]	5 days	Time from infection to infectious
	Infectious period[1]	3.3 - 5 days	Duration of infectiousness
	Infection detection rate[3]	15%	1 confirmed case becomes ~7 initial infections
	Percent asymptomatic[1]	50%	Infected individuals that don't exhibit symptoms
Resources	Onset to hospitalization[1]	5 days	Time from symptoms to hospitalization
	Hospitalization to ventilation[1]	3 days	Time from hospitalization to ventilation
	Duration hospitalized	8 days	Time spent in the hospital [4]
	Duration ventilated[2]	14 days	Time spent on a ventilator
	Percent hospitalized[1]	5.5% (~20% of confirmed)	Symptomatic individuals becoming hospitalized
	Percent in ICU[1]	20%	Hospitalized patients that require ICU
	Percent ventilated[1]	70%	ICU patients requiring ventilation
	Percent Fatality	1.35%	Symptomatic individuals who die

1 CDC COVID-19 Modeling Team. "Best Guess" scenario. Planning Parameters for COVID-19 Outbreak Scenarios. Version: 2020-03-31.
2 Up-to-date. COVID-19 Critical Care Issues. https://www.uptodate.com/contents/coronavirus-disease-2019-covid-19-critical-care-issues?source=related_link (Accessed 13APRIL2020)
3 Li et al., *Science* 16 Mar 2020:eabb3221 https://science.sciencemag.org/content/early/2020/03/24/science.abb3221 (Accessed 13APRIL2020)
4 Personal communications, UVA Health and Sentara (~500 VA based COVID patients)

Calibration Approach

- **Data:**
  - County level case counts by date of onset (from VDH)
  - Confirmed cases for model fitting
- **Model:** PatchSim initialized with disease parameter ranges from literature
- **Calibration:** fit model to observed data
  - Search transmissibility and duration of infectiousness
  - Markov Chain Monte Carlo (MCMC) particle filtering finds best fits while capturing uncertainty in parameter estimates
- **Spatial Adjustments:** VDH districts grouped to 3 tiers of growth during the Pause, with similarly scaled reductions then applied to the groups of districts
- **Project:** future cases and outcomes using the trained particles

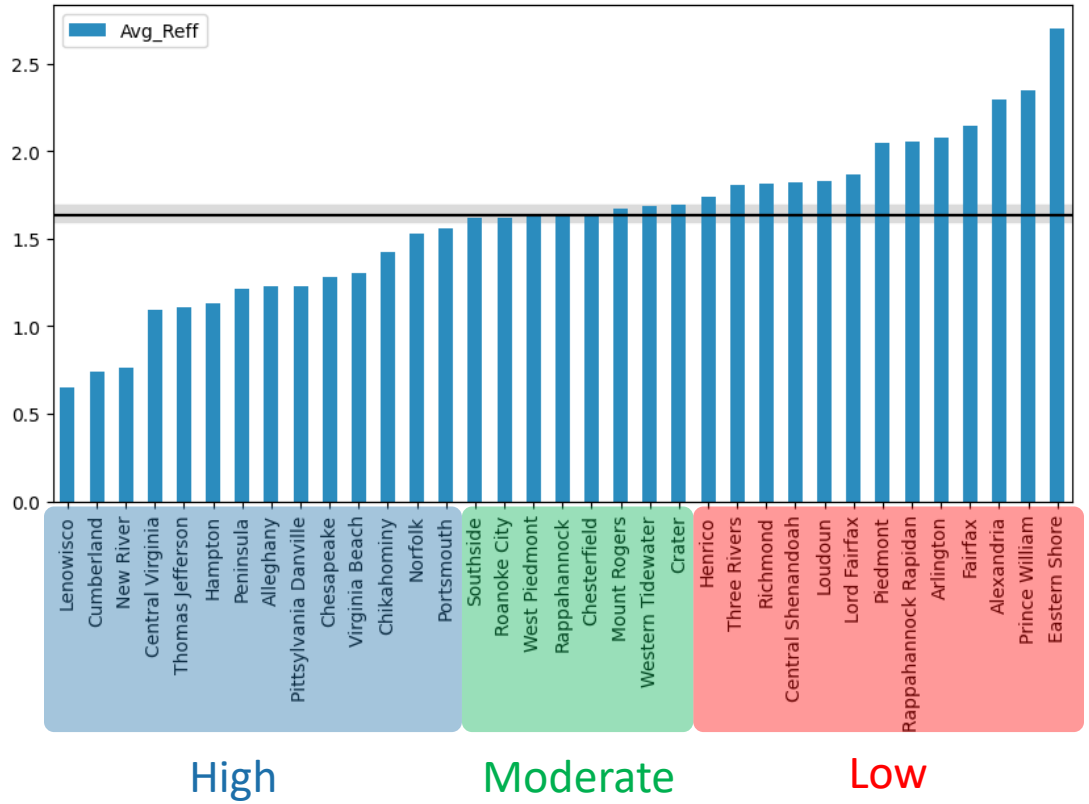


Accessed 10pm July 28, 2020
https://www.vdh.virginia.gov/coronavirus/

Spatial Adjustments at District Level

District Specific adjustments based on Growth during Pause

- Group districts by their mean growth from mid-April to mid-May (using model based R_{eff})
- Assign reductions during Pause, and beyond, to members of these groups
- Low reduction = 40%
- Moderate reduction = 45% (previous level)
- High reduction = 55%



Supplemental Slides

Recent Parameter Validation

New York State announced sero-prevalence survey results on May 2nd

- 15,000 antibody tests conducted randomly through the state at grocery stores
- **Total Attack Rate**: 12.3%

Estimation of undetected infections

- Total infections in NY = 2.46M, total of 300K confirmed cases
- Confirmed case detection = 12% of infections (close to 15% used in model)

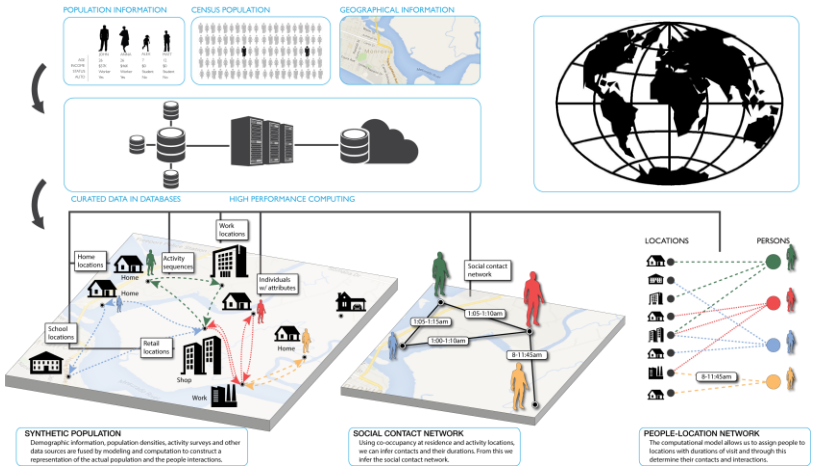
Estimation of hospitalizations from infections

- Total infections in NY = 2.46M, total of 66K hospitalizations
- Hospitalizations = 2.7% of infections (close to 2.25% used in model)

Agent-based Model (ABM)

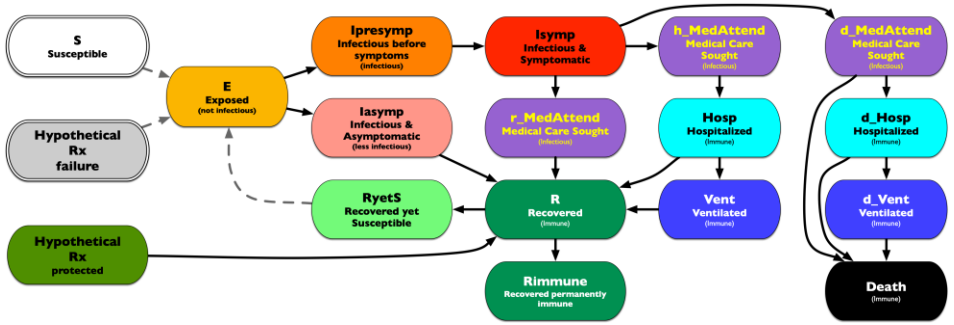
EpiHiper: Distributed network-based stochastic disease transmission simulations

- Assess the impact on transmission under different conditions
- Assess the impacts of contact tracing



Synthetic Population

- Census derived age and household structure
- Time-Use survey driven activities at appropriate locations



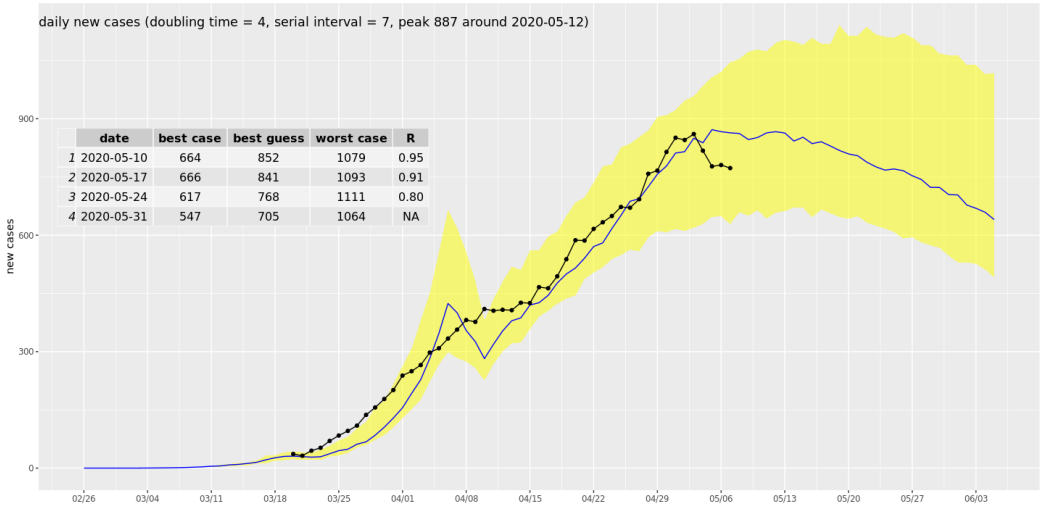
Detailed Disease Course of COVID-19

- Literature based probabilities of outcomes with appropriate delays
- Varying levels of infectiousness
- Hypothetical treatments for future developments

ABM Social Distancing Rebound Study Design

Study of ”Stay Home” policy adherence

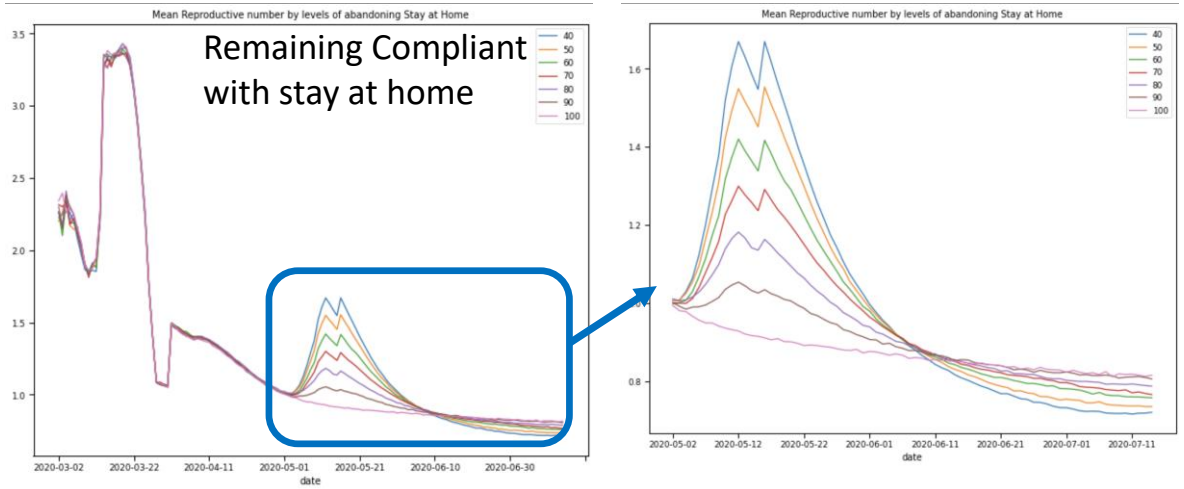
- Calibration to current state in epidemic
- Implement “release” of different proportions of people from ”staying at home”



	date	best case	best guess	worst case	R
1	2020-05-10	664	852	1079	0.95
2	2020-05-17	666	841	1093	0.91
3	2020-05-24	617	768	1111	0.80
4	2020-05-31	547	705	1064	NA

Calibration to Current State

- Adjust transmission and adherence to current policies to current observations
- For Virginia, with same seeding approach as PatchSim

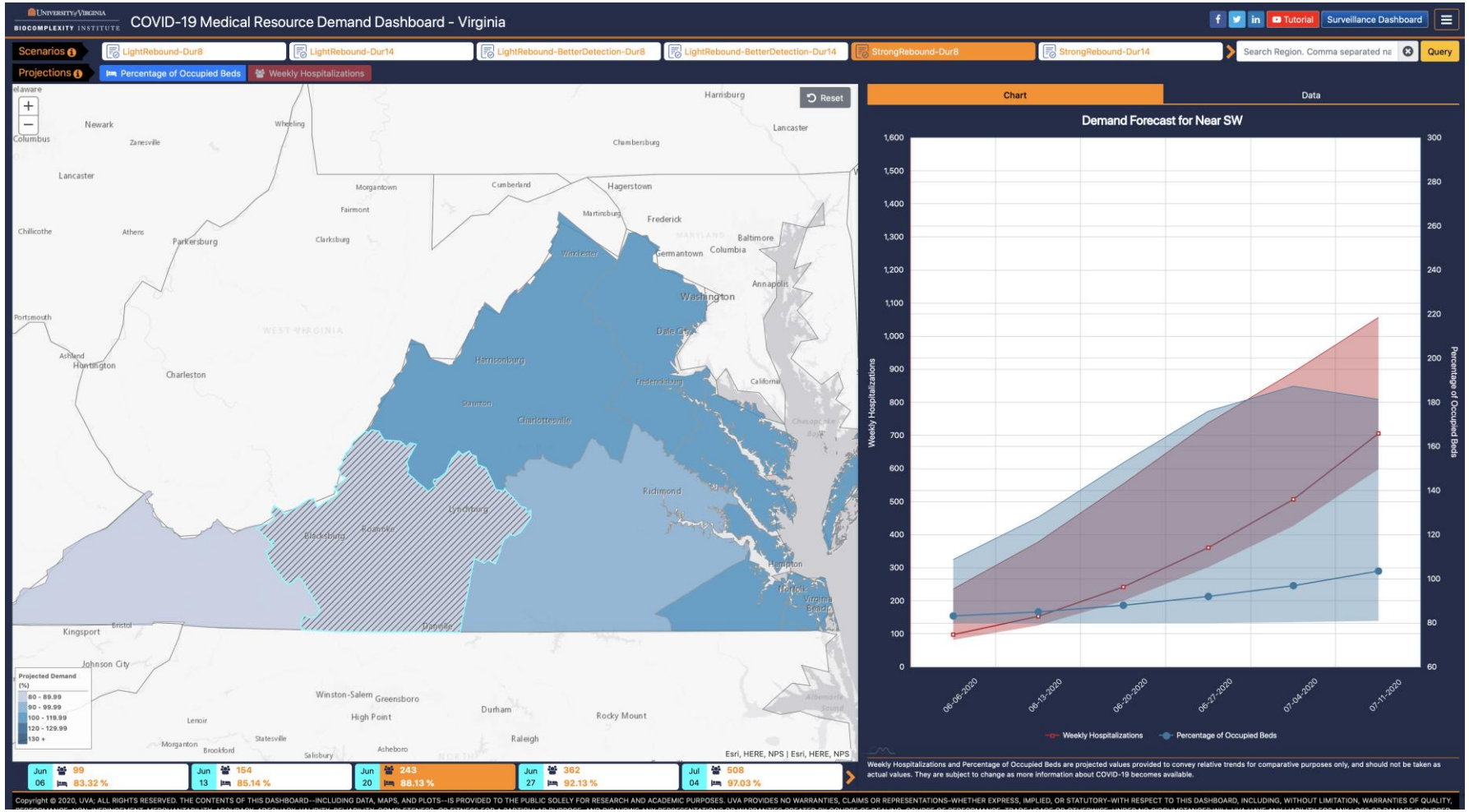


Impacts on Reproductive number with release

- After release, spike in transmission driven by additional interactions at work, retail, and other
- At 25% release (70-80% remain compliant)
- Translates to 15% increase in transmission, which represents a 1/6th return to pre-pandemic levels

Medical Resource Demand Dashboard

https://nssac.bii.virginia.edu/covid-19/vmrddash/



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